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Technology Development Roadmaps: A Bibliometric Analysis of Scientific Literature

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Cezary Winkowski[1]

Abstract:

Purpose: *The purpose of this article was to identify research sub-areas and to investigate methodological deficiencies in technology development roadmaps.*
Design/Methodology/Approach: *For achieving the objective of this study, a critical analysis of literature and bibliometric analysis was carried out, through the analysis of 2610 relevant Scopus-indexed documents. The time frame of the analyzed period covered the years 1984-2019. On these grounds, a bibliometric map was developed using the VOS mapping technique – visualization of similarities.*
Findings: *The analysis of interrelated key terms made it possible to identify clusters as research sub-areas related to the subject of technology roadmaps. The names of clusters were proposed, which made it possible to identify research sub-areas and main research issues, in which the authors of the publications used technology development roadmaps. The main areas in which technology development roadmaps are used include among others: estimating the potential environmental impact of technology change and anticipating its effects, determining the future of technological progress in companies, at various levels of government agencies and other organizations or designing directions of technology development in the context of sustainable development.*
Practical implications: *This issue is important not only in the theoretical aspect, but also to increase the awareness of companies to help further improve strategic management related to technology management.*
Originality/Value: *It was proposed to develop a methodology for the designing of technology development roadmaps, which will allow for a comprehensive look at the analyzed problem and will enable to determine the directions of technology development in a comprehensive way.*

Keywords: *Technology roadmaps, road-mapping, technology development, technology management, cluster analysis, bibliometrics, co-word analysis.*

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[1]*Bialystok University of Technology, Faculty of Engineering Management, ORCID ID: 0000-0002-1470-1874, e-mail: c.winkowski@pb.edu.pl*

1. Introduction

The dynamics of changes in the area of innovative technologies, constant development of industry, as well as increasing globalisation and growing competition, force to implement and use new, more efficient, and economically viable technologies or improve existing ones. One of the key factors that prove the value of an enterprise are its technical and technological resources, including knowledge and innovations. Technical progress, especially development of technologies, their implementation in production processes are an important lever of competitiveness and a leading force of economic development (Grudzewski and Hejduk, 2008; Schumpeter, 1949; Garfield, 1988; Zwierzyński, 2018).

In a situation of growing demand for innovative technologies and a broad market for technology trading, the issue of effective technology management is becoming increasingly important. The management of technologies in the long-term perspective, due to the complexity and global pace of change, is a difficult process, requiring the consideration of specific systems and processes, adapting to the market and industrial needs, both in the present time and in the long-term perspective (Magruk, 2011). According to Klincewicz (2010), an important problem of technology management is, among others the understanding the emerging new technologies and their significance for the current activity of the enterprise, the identification of opportunities and threats related to technology development and the selection of technologies of strategic and tactical importance. The use of strategic planning methods is helpful in eliminating the above-mentioned problems, especially in the long-term perspective. One of this type of tools is the technology development roadmap (Popper, 2008; Nazarko and Ejdys, 2011).

Technology development roadmap may be helpful in the process of identifying a technology that is of real or potential relevance to the company. It can also be useful in the process of technology selection, where decision making is required, preceded by the definition of priorities adopted by the company at the strategic level. It is also useful in the process of acquiring knowledge resulting from technology development (Halicka, 2014). Choosing the right technology largely determines the competitive advantage of companies. Technologies are also the basis of modern manufacturing processes, enabling to meet the needs of society. The awareness of the need for technology development has become widespread, as evidenced by international programmes supporting the development of technology (Halicka, 2016).

The method of technology development roadmap is a subject of interest of many authors who disseminate their research papers in technology management journals such as "Technological Forecasting and Social Change", "Technovation", "Service Business". The analyzed method is widely used in foresight projects, especially at the sector and corporate level (Phaal *et al.*, 2001). This method was the most appropriate for use in e.g., sectoral foresight in the area of sustainable development

(Metodologia, 2011; Mazurkiewicz, 2010). In the literature on the subject there are also examples of using this method to support management and strategic planning, especially in enterprises (Nazarko and Ejdys, 2011) and research units (Geest, 2010; Willeke, 2002). Although the technology development roadmap method has been in use for more than 30 years, it is still being developed through the adaptation of new concepts, indicating the possibility of linking with other methods of strategic analysis or new areas of application. This document responds to a knowledge gap in the use of the technology development roadmaps. To fill this research gap, this paper conducts a bibliometric analysis of the literature in the field of technology development roadmaps from 1984 to 2019, and mainly intends to answer the following research questions:

Q1: What are the methodological deficiencies in technology development roadmaps?
Q2: What are the hot research themes in the field of technology development roadmaps?
Q3: What is the relationship between these hot research themes?
Q4: What are the main research directions in the field of technology development roadmaps?

This paper is organized in two main parts, as follows: after the introduction, the literature review is presented. In this section the methodological deficiencies in technology development roadmaps have been identified, thus answering the first research question (Q1). Then the materials and methodology are explained. In the second part of the article the interest in the subject matter studied over the years was analyzed. Next the co-occurrence and co-classification of words was evaluated in publications. A bibliometric map was developed, which is a visualization of the results of the analysis in the field of co-occurrence of words. In this part of the work, author focused on an in-depth analysis of the articles and interpretation of the created bibliometric map. The names of clusters were proposed, which made it possible to identify research sub-areas and main research issues, in which the authors of the publications used technology development roadmaps, thus answering Q2 and Q3. Next the important findings were discussed, and suggestions for future research were proposed, thus answering Q4. The paper is ended with the conclusions from the bibliometric analysis.

2. Literature Review

2.1 The Contemporary Approach to Technology

Technologies are widely used and considered in different areas of human life and functioning (Halicka, 2016). In the literature on the subject one can find many definitions of technology. Technology can be perceived in an enterprise through the prism of devices, equipment (Orlikowski, 1993). It can also be considered in the context of methods used in the enterprise (Young, 1989). In the opinion of the

above-mentioned authors, a technology may be both a final product and a device used to produce a product or service, or a component of a manufacturing process.

According to Stiegler (1998), technology is a so-called organized inorganic matter, functioning around organic and inorganic entities. Lunarski (2009), Schlie (1996), Santarek (2008), Lowe (1999), believe that the technology is not only physical objects, but also several actions taken in order to produce the final product. All these activities can be undertaken based on available knowledge (scientific and empirical), which is the basis of each technology. According to Steele (1989), Trott (2008) and Pacey (1983) technology is the knowledge and skills used by an enterprise, necessary to produce goods and services. Dosi (1982), Jasiński (2006), Burgelman *et al.* (2001) consider technology to be "know-how", that is to say, theoretical, practical knowledge and the ability to apply it to production and to develop and deliver products and services to end users.

Technology can take materialized form (products) and non-materialized (research results, designs, techniques) and be expressed in raw materials, processes, procedures, methods, devices and tools, factories that use this knowledge. Kaczmarek (2001), and Gawlik *et al.* (2013), define technology as a set of sciences which main purpose is to study manufacturing processes and to identify and formulate the laws governing these processes and to develop the basis for optimizing manufacturing processes.

In the literature, technology is sometimes treated as a kind of system. According to Lunarski (2009), this system consists of elements (machines and technological devices) connected in a specific way (transport, information or other systems) and performing a strictly defined function (production of planned products and services) and having specific links to the environment. Technology can also be presented as a system, distinguishing the following five components (Sharif, 1986; Smith and Sharif, 2007; Sharif, 2012):

- technoware (artefacts, tools, equipment, machines, constructions, materials, technical equipment);
- humanware (experience, personal qualifications, competences not only technical but also creative, ingenuity, decision-making skills);
- orgaware (methods of organisation, structures and ways of systematic integration and coordination of activities and resources);
- infoware (a specific system of knowledge about production - drawings, diagrams, patterns, theories, technical parameters, manuals, guides, plans, charts, tables);
- cysnetware (virtual space, virtual cloud computing).

Halicka (2016) also perceives technology as a system, identifying seven components of the technology:

- hardware (product - used by the end user; machine, device – used to produce a product or service; research and testing equipment; component – element of the manufacturing process);
- software (programs controlling the operation of the equipment);
- net (software and hardware enabling the free flow of technology related data, and with the entire manufacturing process);
- orgaware (methods, structures, rules and methods of operation, resources and software);
- humanware (creators and users of technology with their skills and competencies);
- database (a collection of data and information on a given technology);
- virtual space.

According to the author, the above-mentioned approach to technology is the most comprehensive.

2.2 Classification of Technologies

During the literature review it was noted that there are different criteria for technology classification. For further analysis, the classification of technologies by the degree of impact on the competitiveness of enterprises was adopted (Molina, 1998) as basic, key, progressive and emerging.

Basic technologies are widely used in industry and often form the basis of many companies' activities. They are essential for the proper functioning of an organisation, but do not offer a significant competitive advantage. Key technologies, on the other hand, usually provide a richer offer, higher quality products, higher efficiency, or lower costs. So, these are the technologies that determine the competitive advantage. Technologies that set the pace are at an early stage of development and can provide a competitive advantage only in the future. On the other hand, emerging technologies require a long, costly, and often a risky process of development and improvement. They may bring a significant competitive advantage in the undefined future (Goodman and Lawless, 1994; Durlik and Santarek, 2016).

2.3 Technology Road-mapping

The technology development roadmap presents development visions for selected technologies in terms of market, technological and human potential. It identifies precise objectives and helps to focus on the resources necessary to implement the technologies. It is important due to increasingly limited R&D investments, which can be used more effectively (Fiedeler *et al.,* 2004; Kononiuk and Gudanowska, 2013; Phaal *et al.,* 2004).

Roadmaps may take a variety of graphic forms. They are presented as histograms, tables, graphs, flow diagrams or text. The Phaal *et al.*'s (2011) concept should be considered in the design of the technology development roadmaps, as it is most used. This concept consists, among others the identification of: priority technologies; products; components that are necessary in the process of creating and implementing priority technologies; research directions allowing for development or production of priority technologies; potential and the resources that will allow to implement the desired vision of technology development (Phaal *et al.,* 2011).

Although the ways of visualizing technology development roadmaps present quite different approaches, in the end they lead primarily to putting the knowledge about technology in a broad context considering the time horizon. The technology development roadmap allows for the analysis of the technology in the long term and allows for the reflection of the links that exist between the development of technology, and progress in other areas (Phaal *et al.,* 2004). The methodology of creating technology development roadmaps requires an integral approach using other techniques and methods such as scenario method, SWOT analysis, Porter's Five Forces analysis, STEEPVL analysis (Phaal, 2011).

2.4 Examples of Using Technology Road-mapping in the Literature

The technology roadmapping method was developed over 30 years ago by Motorola in the area of production planning (Kononiuk and Gudanowska, 2013). In the publication "Motorola's use of the product technology roadmap" of 1984, Harring presents a roadmap that is a comprehensive description of the product line of the past, present and future (Harring, 1984). Two years later, an article was published in which Winblade (1986) describes a roadmap developed by NASA for long distance supersonic cruises. In turn, Litman *et al.* (1992) in their publication summarizes the roadmap for the implementation of the advanced development of Proton Exchange Membrane (PEM) Regenerative Fuel Cell (RFC) to ensure long life or portable applications of power systems on the surface of the Moon and Mars.

Spencer *et al.* (2019), Cresto *et al.* (2019), also describe the use of roadmaps in the context of the space industry, and Volodin *et al.* (2019) emphasize the importance of roadmaps for the scientific and technological development of the space and aviation industry. Another example presented in the literature is the use of technology development roadmaps in the context of health care (Re, 1994; Varnado, 1994; Bonventre *et al.,* 2019) and in the pharmaceutical industry (Borschiver *et al.,* 2019).

Xie *et al.* (2019), Zhang *et al.* (2018), Hackler and Prack (2019), describe the use of the roadmaps to design the development of semiconductor technologies. In the literature there are also examples of roadmapping application in the context of nanotechnology (Kononiuk and Gudanowska, 2013; Lahoti *et al.,* 2018; Bhati *et al.,* 2019). In turn, in the study titled *"Technology roadmapping in security and defence foresight",* an assessment of roadmaps as a political instrument for the defence

industry was conducted (Vicente and Martinez-Sanchez, 2018). In the context of the defence industry, the use of technology roadmapping was also presented in the Lu and You (2018) study. Still another area of application of the technology development roadmaps discussed in the literature is the energy sector (Daim *et al.,* 2018). The method analyzed is widely used in foresight projects, particularly at the sector and corporate level (Phaal *et al.,* 2001). In the literature on the subject there are also examples of using this method to support management and strategic planning, especially in enterprises (Nazarko and Ejdys, 2011) and research units (Geest, 2010; Willeke, 2002).

The above examples of road-mapping application confirm that it is a tool that can be used in various initiatives. However, while reviewing the literature, it was noted that many authors in their publications point out some methodological deficiencies in the design of technology development roadmaps and stress the need to develop this methodology. As Kim *et al.* (2018) rightly point out, technology is changing fast and customers are looking not only for products and services but also for experiences. The traditional approach to strategic planning using technology development roadmaps is no longer enough. Among the challenges related to the application of technology development roadmaps, the following stand out (Kerr and Phaal, 2019; Son and Lee, 2019; Gerdsri *et al.,* 2019; Son *et al.,* 2020; Hofer *et al.,* 2019; Volodin *et al.,* 2019; Lahoti *et al.,* 2018):

- barriers to defining the requirements for a given roadmap initiative and developing an agreed way of expressing what is "needed – expected" and what can be "delivered" (within the time frame and with the resources available);
- an important element of the technology development roadmap is to establish relations between market, product and technology elements (despite the importance of analyzing such relations, few previous attempts were made to solve this problem);
- in today's rapidly changing market and economic conditions, organizations need to adapt effectively because changes in the internal and external environment of companies always have an impact on strategy and technology development roadmaps;
- there is a limitation in existing studies that internal and external uncertainty factors are not taken into account;
- the current approach is mainly based on technology assessments which focus on current preparedness and maturity of technology or qualitative assessment of potential. This approach does not quantify the future development potential of new or immature technologies;
- one of the main difficulties during the implementation of the method is the multitude of specific forms of roadmaps, which often must be adapted to specific needs and contexts.

Based on rationale from the literature in the field of technology development roadmaps, it can be stated that there is no holistic view on designing directions of technology development. In the methodology of designing of technology development roadmaps is not considering all seven technology components such as: virtual space, databases, software, hardware, net, orgaware, humanware. Due to the importance of technology development roadmaps, among others in technology management, it seems justified to develop the methodology of creating technology development roadmaps by incorporating these technology components.

There is a need to develop a new approach to predicting potential directions of technology development in different time horizons. According to the author, the integration of all seven components of the technology and internal and external uncertainty factors with the methodology of creating technology development roadmaps will enable a holistic view of the analyzed problem and will enable the design of technology development directions in a comprehensive manner. In the further part of the study, the results of bibliometric analysis of technology development roadmaps are presented.

3. Materials and Methods

In order to assess the dynamics of interest in the subject of technology development roadmaps, a bibliometric analysis was conducted. The basic source of data in the bibliometric analysis are bibliographic databases. The database was selected due to its size and availability. The bibliometric analysis was carried out in two stages.

3.1 Stage I – Data Collection

The publication review was carried out in the Scopus database. The timeframe of the study was “open-ended” in the document search, the relevant data appear from the period of 1984 to present (December 2019). The phrase based on which the Scopus search was conducted was "technology roadmaps" contained in the titles, abstracts, and keywords. As a result of such a search, 2610 articles were found.

3.2 Stage II – Analysis of Co-occurrence of Words

At this stage of the bibliometric analysis, the co-occurrence and co-classification of words was evaluated in publications. A method of word co-occurrence analysis was used, based on counting the sequence of words appearing in the text. This method allows the classification of research sub-areas based on co-occurrence of words. The results obtained by means of bibliometric analysis are usually presented in the form of a map showing relations between individual elements (Gudanowska, 2015; Gudanowska, 2017; Siderska and Jadaa, 2018).

A bibliometric map was created using the VOS mapping technique – visualization of similarities. VOS is aimed at locating objects in a low-dimensional space in such a

way that the distance between any two objects reflects the similarity or the most accurate connection of these items (Szpilko, 2017). The map was developed using VOSviewer software, which is available at www.vosviewer.com. The created map reflects the co-occurrence of words and their co-classification in publications (Winkowska *et al.*, 2019). The size of the circles reflects the number of occurrences of a specific word, while the distance between the circles depends on the number of co-occurrences (Halicka, 2017). In the analyzed text, the frequency of word pairs is counted.

This makes it possible to identify phraseological relationships or the regularity of word co-occurrence. Co-occurrence of words may signal the existence of research sub-areas or identify the premises that determine the directions of further development of a given research area. The results of the analysis allow to identify research sub-areas both in one area, as well as and in interdisciplinary areas (Dobrzyński *et al.*, 2013). In the Scopus database, it is possible to save bibliographic data in the form of files, which can then be directly processed using VOSviewer.

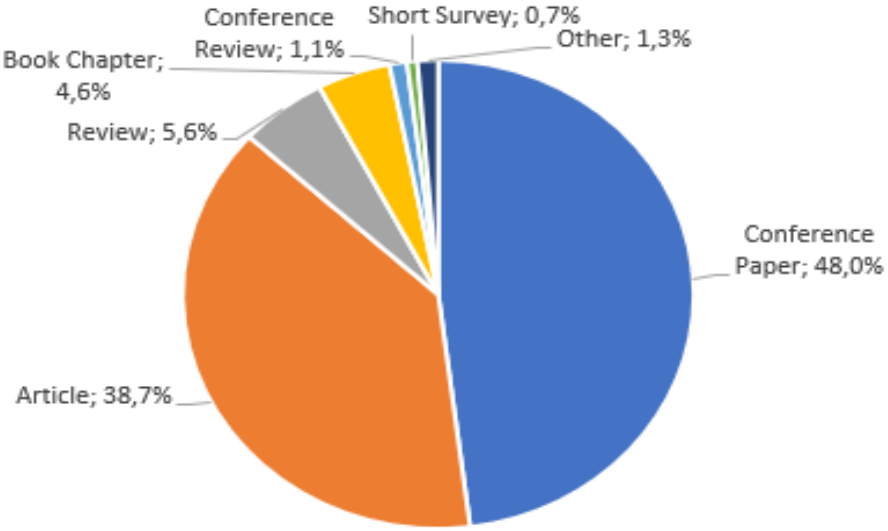
4. Results

Exploration of the Scopus database resulted in finding 2610 publications registered in the database. The phrase based on which the database was searched was "technology roadmaps", containing in the titles, abstracts, and keywords. The largest part of studies was (Figure 1) conference papers (48%) and articles (38.7%). Most publications were written in the United States (1091 studies). Many publications were also prepared in China, Germany, Japan, Great Britain, and France.

The next step was to analyze the interest in the subject matter studied over the years. The time frame of the analyzed period covered the years 1984-2019. The first publication on technology roadmaps registered in the database was created in 1984 ("Motorola's use of the product technology roadmap"). Analyzing Figure 2, it can be observed that from the moment of the first publication on technology roadmaps until 1993, there were not many articles related to the subject under study. Since 1994 there has been a stable increase in the number of publications, until 2006, when most of them appeared (161). From 2007 to 2019, the number of appearing articles remained at a constant average level. The average annual number of publications over those years was 129.

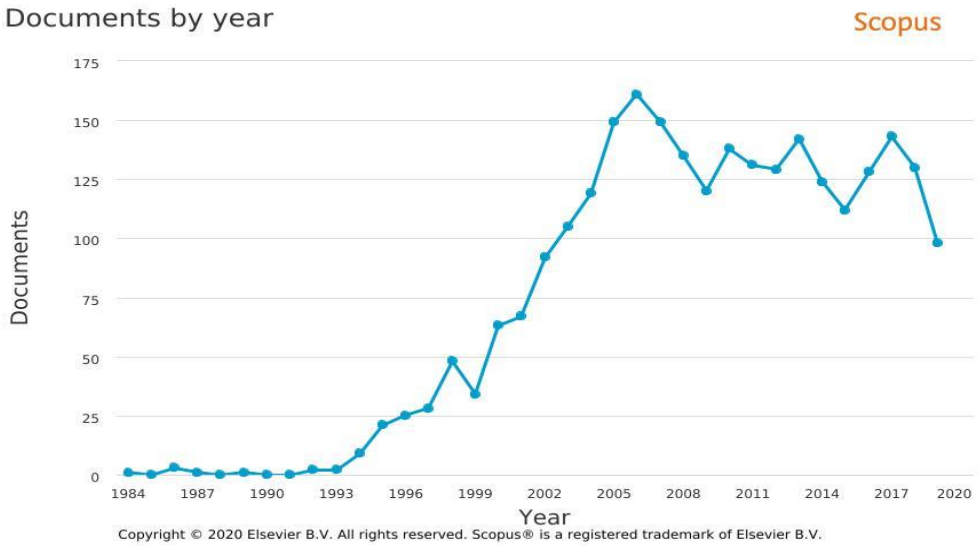
In the next stage, the identified publications were analyzed in terms of research areas (Figure 3). The concept of technology roadmaps is an area of research in many scientific disciplines. The areas in which this field is most often addressed include engineering sciences (32.6%). Scientific disciplines in which this field also occupies an important place are material science (15.7%), physics and astronomy (13%) and IT (11.2%).

Figure 1. *Results of the search in the Scopus database — the document type criterion (indexed from 1984 to 2019)*



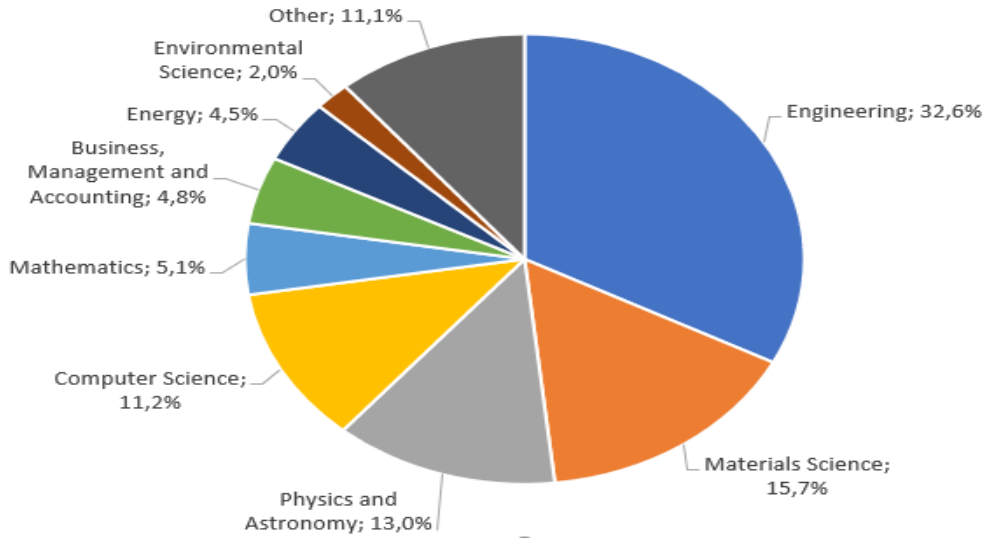
Source: *Author's elaboration based on data from Scopus database.*

Figure 2. *Number of publications in the field of „technology roadmaps" in Scopus database (indexed from 1989 to 2019)*



Source: *Author's elaboration based on data from Scopus database.*

Figure 3. *Identified publications in terms of a subject area in Scopus database (indexed from 1984 to 2019)*

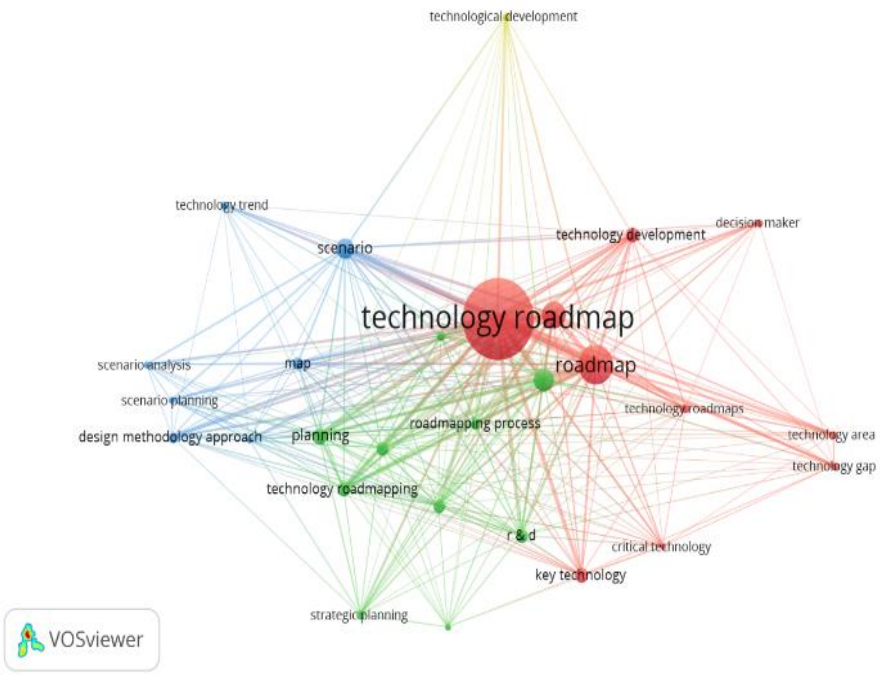


Source: *Author's elaboration based on data from Scopus database.*

In the last stage of the bibliometric analysis, a bibliometric map was developed, which is a visualization of the results of the analysis in the field of co-occurrence of words using VOSviewer software. The results of the analysis are presented in Figure 4. The analysis of 28 interrelated key terms made it possible to identify clusters as research sub-areas related to the subject of technology development roadmaps:

- cluster 1 – contains 10 simultaneously occurring terms: *critical technology, key technology, decision maker, strategy, roadmap, technology development, technology area, technology gap, technology roadmap, technology roadmaps;*
- cluster 2 – contains 7 simultaneously occurring terms: *design methodology approach, map, scenario, scenario analysis, scenario planning, technology management, technology trend;*
- cluster 3 – contains 10 simultaneously occurring terms: *enterprise, management, strategic planning, R&D, road-mapping, technology planning, technology road-mapping, road-mapping process, planning, strategic technology roadmap;*
- cluster 4 – contains one term: *technological development* – due to the fact that there is only one term in this cluster and it is equivalent with the term *technology development* (cluster 1), it was excluded from the subject of further analysis.

Figure 4. *Map of sub-areas related to the technology development roadmaps*



Source: *Author's elaboration.*

In the next part, the work focused on an in-depth analysis of the articles and interpretation of the created bibliometric map. The names of clusters were proposed, which made it possible to identify research sub-areas and main research issues, in which the authors of the publications used technology development roadmaps (Table 1).

Table 1. *Sub-areas and main issues of technology roadmaps research*

Cluster	Research sub-areas	Main research issues
1	Technology Analysis	Analysis of patent development patterns (Jeong and Yoon, 2015; Yu and Zhang, 2019; Trappey et al., 2019; Zhou et al., 2019; Yang et al., 2019); Identification of key technologies, key technologies in the context of creating "smart products" and analysis of "smart cities" technologies (Schulmeyer, 1986; Yu et al., 2019; Lu et al., 2019; Romanski and Daim, 2019; Lai et al., 2019; Cresto et al., 2019; Dede et al., 2019); Estimating the potential environmental impact of technology change and anticipating its effects (Gomes et al., 2019; Shim et al., 2019; Matani, 2019; Dooley, 2017).

2	Designing Technology Development	Determining the future of technological progress in companies, at various levels of government agencies and other organizations (Cho et al., 2016; Borschiver et al., 2019; Hofer et al., 2019; Pershad, 2018); The technology development roadmap as a key tool for innovative activity at different levels of management (enterprise, inter-industry, industrial and organizational) (Volodin et al., 2019; Rashdan et al., 2019; Letaba et al., 2018); Designing directions of technology development in the context of sustainable development (Yao et al., 2019; Lee et al., 2019; Gallegos and Daim, 2017; Ng and Shukor, 2016; Li et al., 2016; Mose and Weinert, 2015).
3	Technology Management	R&D management (Shim et al., 2019; Yu and Li, 2018; Zhou et al., 2019; Vicente and Martinez-Sanchez, 2018; Behling et al., 2019; Kim and Choi, 2018); Using the roadmap as a tool for integration and strengthening of existing business processes and as a platform to support and synchronizing management toolkits for the entire organization (Kerr and Phaal, 2019; Zarrin and Daim, 2019; Son and Lee, 2019; Gerdsri et al., 2019).

Source: *Own.*

In the cluster defined as *Technology Analysis*, one of the leading directions of research conducted by the authors of the publications, is to use technology development marches to analyze patterns of patent development. Patent technology development roadmaps enable the management of an organization to develop patent strategies to obtain a valuable basic patent, which can become a business model with long-term profitability (Bhati *et al.,* 2019). Another important subject of research within the analyzed cluster is the identification of key technologies. This is a particularly important issue in the context of achieving competitive advantage. The technology development roadmap helps to identify which technologies should be developed in order to achieve, for example, higher quality of products. The researchers emphasize that it is also extremely important to estimate the potential impact of technology change on the environment and to predict the effects of these changes.

In the cluster *Designing Technology Development*, among the main research topics were those concerning the determination of the future of technological progress and the use of the technology development roadmap as a key tool for innovative activity at different levels of management (enterprises, inter-industry, industrial and organizational). This is another indication of the importance of technology development roadmaps, so it seems justified to develop the methodology of creating technology development roadmaps. Another research topic within this sub-area is the design of technology developments in the context of sustainable development. The method of technology development roadmaps was the most appropriate for use

e.g., in sectoral foresight in the area of sustainable development (Stiegler, 1998; Lunarski, 2009).

In the last cluster *Technology Management*, two main research themes were identified. The first one is management of the R&D sphere. The technology development roadmap is one of the useful tools for managing R&D planning. Technology development roadmaps developed in various R&D programmes influence strategic behaviour of enterprises. However, practitioners have some difficulties in finding practical guidelines and systematic processes for developing technology development roadmaps applicable to R&D planning in each organization.

This is another indication of the need to improve the methodology of creating of technology development roadmaps. The second research topic is the use of the roadmap as a tool to integrate and strengthening of existing business processes and as a platform supporting and synchronizing management toolkits for the entire organization. Technology development roadmaps have a proven track record of supporting an organization in various ways. They have been used in many industrial initiatives, from simple generation of technology roadmaps for a project, through implementation as a tool to integrate and strengthen existing business processes, to acting as a platform supporting and synchronizing management toolkits for the entire corporation and to creating international, consensus-based, multi-organization technology development roadmaps (Kerr and Phaal, 2019).

4. Discussion

In this paper a bibliometric analysis of the literature in the field of technology development roadmaps through the analysis of 2610 Scopus-indexed articles published from 1984-2019 was conducted. In general, the review suggests that the technology development roadmaps knowledge base remains an emergent field of study that stills draws attention from diverse groups of international scholars in various fields. Importantly, this bibliometric review of the international research answers the four research questions it set out to investigate and advances intellectual insights into the pattern, landscape, and composition of the body of knowledge in the technology development roadmaps. The findings may provide several scholarly benefits as well as broaden our understanding of the technology development roadmaps knowledge base in the existing literature, as discussed in sequence.

Representative research themes, such as, “analysis of patent development patterns”, “identification of key technologies”, “estimating the potential environmental impact of technology change and anticipating its effects”, “technological progress”, “designing directions of technology development in the context of sustainable development”, or ”R&D management” have gradually penetrated into the field of technology development roadmaps.

Although the amount of literature on technology development roadmaps is gradually increasing, some research problems still need to be further explored. Author identified a research gap consisting in the lack of a holistic view of designing directions of technology development. In the methodology for designing of technology development roadmaps is missing all seven technology components such as: virtual space, databases, software, hardware, net, orgaware, humanware. In addition, internal and external uncertainty factors are not considered. There is a need to develop a new approach to anticipating potential technological developments in different time horizons.

5. Conclusions

Based on the conducted research, it can be concluded that although the technology development roadmaps have been used for over 30 years, it should be further developed. The importance of technology development roadmaps is confirmed by the sub-areas of research related to the analyzed subject matter identified by the author. Based on the review and critical analysis of literature and bibliometric analysis of technology development roadmaps, the author also identified a research gap consisting in the lack of a holistic view of designing directions of technology development. In the methodology for designing of technology development roadmaps is missing all seven technology components such as: virtual space, databases, software, hardware, net, orgaware, humanware. In addition, internal and external uncertainty factors are not considered.

Due to the importance of technology development roadmaps, among others in technology management, it seems justified to develop a methodology for creating technology development roadmaps by incorporating all technology components. There is a need to develop a new approach to anticipating potential technological developments in different time horizons. According to the author, the integration of all seven technology components and internal and external uncertainty factors with the methodology for creating technology development roadmaps will enable a holistic view of the analyzed problem and will enable the design of directions of technology development in a comprehensive manner. The research hypothesis will be subject to theoretical and empirical verification as part of further research conducted by the author.

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